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**A TECHNIQUE FOR
MEASUREMENT OF SWELLING PRESSURES OF MONTMORILLONITE
UNDER DEPRESSED TEMPERATURES**

(SOME SHEARING CHARACTERISTICS OF FROZEN SOIL)

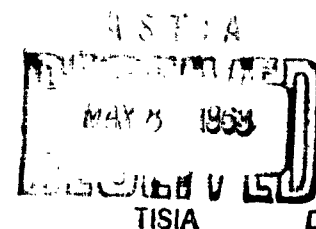
(PART 2)

403 002

by

RAYMOND YONG and L.O. TAYLOR

GEOPHYSICS



REPORT NO. D. Phys. R. (G) Misc. 7

SEPTEMBER, 1961
OTTAWA

UNCLASSIFIED

REPORT NO: D. Phys. R. (S) Misc. 7
PROJECT NO: D9511-28
TITLE: A Technique for Measurement of Swelling Pressures of Montmorillonite under Depressed Temperatures (Some Shearing Characteristics of Frozen Soil) (Part 2)
AUTHORS: Raymond Yong and L. O. Taylor
DATED: September, 1961
SECURITY GRADING: UNCLASSIFIED
INITIAL DISTRIBUTION: APRIL, 1963

- 3 - DSIS Circ; UK Liaison Officer
 - 1 - CDRB
 - 1 - CSC
 - 1 - A/CSc. (S)
 - 1 - D Phys R
 - 1 - D Phys R (S)
 - 1 - DRNL
 - 1 - PNL
 - 1 - DRM London
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**DIRECTORATE OF PHYSICAL RESEARCH
GRANTEE'S REPORT**

**A TECHNIQUE FOR
MEASUREMENT OF SWELLING PRESSURES OF MONTMORILLONITE
UNDER DEPRESSED TEMPERATURES**

(SOME SHEARING CHARACTERISTICS OF FROZEN SOIL)

(PART 2)

by

RAYMOND YONG and L.O. TAYLOR

McGill University

REPORT NO. D. PHYS. R (G) MISC 7

DRB Project No. D9511-28

Received May, 1961

Published September, 1961

OTTAWA

FOREWORD

The following is an initial report on the state of progress of a general study of frozen soil characteristics with specific reference to interparticle action under depressed temperatures, sponsored by the Defence Research Board in the form of a grant-in-aid research (Grant No. 9511-28 (G&C)), to Professor Carleton Craig, Chairman of the Department of Civil Engineering and Applied Mechanics at McGill University, Montreal, Que.

This particular phase of the study is concerned with the evaluation of the behaviour of clay-water systems subjected to depressed temperatures and involving electrochemical forces of interaction.

This report concerns itself with the development of the Gouy-Chapman theory as applied to soils, taking into consideration the effect of temperature and its influence on the dielectric constant; and the instrumentation and procedure for measurement of the resultant swelling pressure which have been designed specifically for this study.

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INTRODUCTION

The characteristics of soil-water interaction under normal temperatures and conditions have been determined. In particular, studies on clay-water systems have been made recently, relative to swelling pressures resulting from interparticle action (Yong and Warkentin 1959; Warkentin et al 1957). However, the effect of depressed temperatures on interparticle action has never been clearly defined or well understood. For an understanding of the mechanics of frost heaving and of the properties and character of frozen soil, it is necessary to understand specifically the interaction phenomena of a clay-water system where the electro-chemical forces play a dominant role.

PURPOSE OF STUDY

To determine the effect of depressed temperatures on the swelling pressure of an oriented pure clay-water system with reference to the interpretation of the role of interparticle forces in Frozen Soil Engineering. This report, however, is restricted to the application of the Gouy-Chapman theory and the instrumentation and procedure for evaluation of swelling pressure as affected by depressed temperatures.

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THEORY

Pure clay is generally defined as that fraction of naturally occurring soil having an effective particle diameter of less than two microns. Commonly occurring clay minerals are usually plate shaped and carry a negative charge of high density at their faces. Interaction between particles of this size is dominated by electro-chemical forces arising from physical reaction between the surface charge of the particle and the media separating the particles. A qualitative and quantitative estimation of particle interaction for certain pure clay water systems can be obtained by the use of the Gouy-Chapman Theory.

The Gouy-Chapman theory considers a negatively charged plate in a media consisting of negatively and positively charged ions. In attempting to establish electrical equilibrium, the positively charged ions flock to the surface of the plate. However, due to the size and thermal energy of the ions, electro-neutrality cannot be established in an ionic monolayer and a diffuse double layer develops in which the electric potential gradually diminishes to zero.

Figures 1 to 3 illustrate the development of the diffuse double layer.

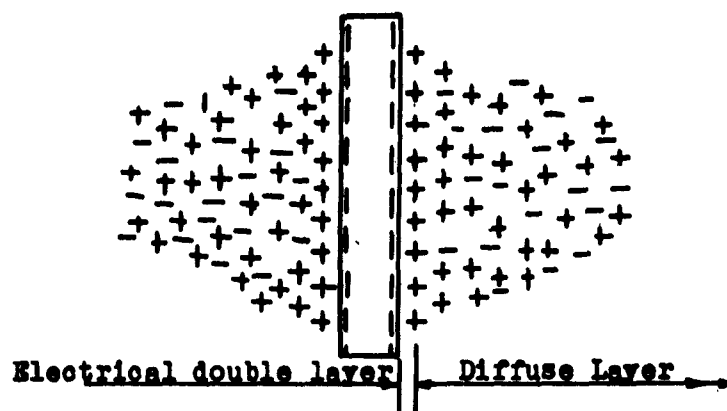


Fig.I. Arrangement of Ions around a negatively charged plate.

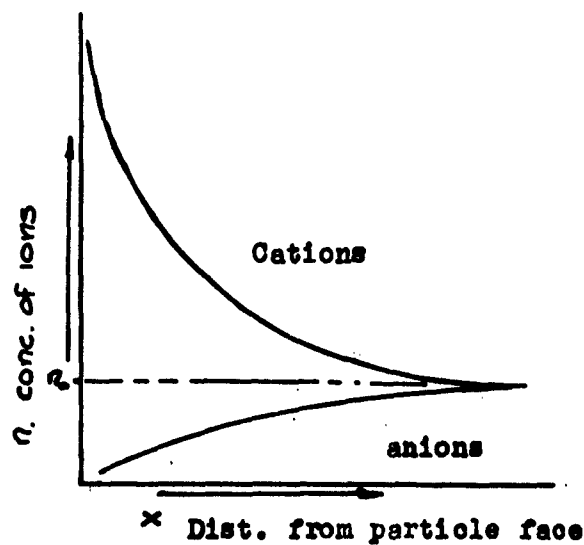


Fig.II. Concentrations of ions with respect to distance from face of particle.

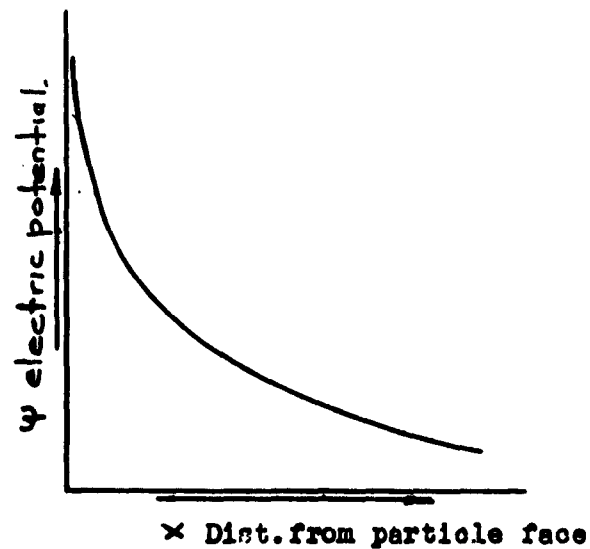


Fig.III. Variation of electric potential in the diffuse double layer.

The basic assumptions of the Gouy-Chapman theory are expressed in the following three equations:

$$\text{The Poisson Equation} \quad - \quad \frac{d^2\psi}{dx^2} = -\frac{4\pi\rho}{D} \quad (1)$$

$$\text{The Boltzmann Equation} \quad - \quad n_i = n_o \exp\left(-\frac{\omega_i}{kT}\right) \quad (2)$$

$$\text{and} \quad - \quad \omega_i = \sum z e \psi_i \quad (3)$$

where D = Dielectric constant

e = electronic charge

k = Boltzmann constant

n_i = No. of ions per unit volume at point "i"

n_o = No. of ions per unit volume in external solution

T = temperature °A

ω_i = work done in bringing anion to point "i"

x = distance from particle face

z = ionic valence

ρ = surface charge density

ψ = electric potential

Equation (1) establishes the relationship between the electric potential ψ and the distance from the particle face.

Equation (2) expresses the ratio between the concentration of ions at point "i" and that of the external or "bulk" solution.

Since the electric potential diminishes to zero in the diffuse layer, then

$$\rho = \sum z e n \quad (4)$$

While the cations are attracted to the plate a certain number of anions will also enter the diffuse double layer and hence equation (4) becomes-

$$\rho = \sum (z^+ e n^+ - z^- e n^-) \quad (5)$$

$$\text{From Eq. (1)} \quad \frac{d^2 \psi}{dx^2} = -\frac{4\pi}{D} \sum (z^+ e n^+ - z^- e n^-) \quad (6)$$

Substituting for (2) in (6) for the case of a symmetrical electrolyte

$$\frac{d^2 \psi}{dx^2} = -\frac{4\pi z^2 e n_0}{D} [\exp(-\frac{ze\psi}{kT}) - \exp(\frac{ze\psi}{kT})] \quad (7)$$

The boundary conditions for Eq. (7) are (refer to Fig. 3)

$$(1) \text{ At the face of the plate i.e. } x \rightarrow 0, \psi \rightarrow \infty \quad \frac{d\psi}{dx} \rightarrow \infty$$

$$(2) \text{ At an infinite distance away i.e. } x \rightarrow \infty, \psi \rightarrow 0 \quad \frac{d\psi}{dx} \rightarrow 0$$

$$\text{Let} \quad y = -\frac{ze\psi}{kT}$$

$$\therefore \frac{d^2 y}{dx^2} = -\frac{ze}{kT} \frac{d^2 \psi}{dx^2} \quad (8)$$

Substituting Eq. (8) in (6)

$$\frac{d^2 y}{dx^2} = \frac{4\pi z^2 e^2 n_0}{DkT} [\exp(y) - \exp(-y)] \quad (9)$$

$$\text{or-} \quad \frac{d^2 y}{dx^2} = \frac{8\pi z^2 e^2 n_0}{DkT} \sinh y \quad (10)$$

$$\text{letting-} \quad K = \sqrt{\frac{8\pi z^2 e^2 n_0}{DkT}} \quad (11)$$

$$\therefore \frac{d^2 y}{dx^2} = K^2 \sinh y \quad (12)$$

$$\text{and on integration } \left(\frac{dy}{dx}\right)^2 = 2K^2 \cosh y + C \quad (13)$$

Solving for "C" by substitution of conditions $y \rightarrow 0, \frac{dy}{dx} \rightarrow 0$ in Equation (13)

$$\frac{dy}{dx} = -K \sqrt{2(\cosh y - 1)} \quad (14)$$

$$\text{rearranging (14)} \quad \frac{dy}{dx} = -2K \sinh(y/2) \quad (15)$$

$$\therefore \int \frac{dy}{2 \sinh(y/2)} = - \int K dx \quad (16)$$

$$\text{and } \ln [\coth(y/4)] = Kx + C \quad (17)$$

Solving for "C" in Eq.(17) by substituting $y \rightarrow \infty, x \rightarrow 0$

$$\ln [\coth(y/4)] = Kx \quad (18)$$

$$\text{or-} \quad y = \ln \left[\coth \left(\frac{Kx}{2} \right) \right] \quad (19)$$

$$\therefore \quad \psi = -\frac{KT}{\epsilon \epsilon_0} \cdot 2 \cdot \ln \left[\coth \left\{ \sqrt{\frac{8\pi \epsilon^2 e^2}{DKT}} \cdot \frac{x}{2} \right\} \right] \quad (20)$$

Eq.(20) can be used to obtain the value of ψ at distance x for any one set of conditions.

Due to the dipolarity of water, a clay particle in water is analogous to the model used in the derivation of Eq.(20). However, it has been assumed that $y \rightarrow \infty$ as $x \rightarrow 0$. This corresponds to a plane of infinite charge at the face

of the plate and although the surface of typical clay minerals carry a relatively high charge density, a small error results in assuming the surface charge density to be infinite. By retaining for mathematical simplicity, the plane of infinite charge density as the origin of x , it is possible to calculate the position at which a plane having the charge density of the clay mineral would occur with respect to the origin. Let x_0 be the distance from the plane to the origin.

$$\text{From Eq. (1)} \quad \sigma^* = \int_0^{\infty} \frac{D}{4\pi} \left(\frac{d^2\psi}{dx^2} \right) dx \quad (21)$$

$$\therefore \sigma = - \frac{D}{4\pi} \left(\frac{d\psi}{dx} \right)_{x=0} \quad (22)$$

From Eq. (15) and rearranging

$$\sigma = \sqrt{\frac{2n_0 DKT}{\pi}} \operatorname{cosech} h.(Kx_0) \quad (23)$$

$$\sigma \approx \sqrt{\frac{2n_0 DKT}{\pi}} \frac{1}{Kx_0} \quad (24)$$

$$\therefore x_0 = \frac{DKT}{2\pi z e \sigma} \quad (25)$$

In soil water interaction, however, an overlapping of the diffuse double layer occurs if the particles are in close proximity, and the boundary conditions must be revised for the solution of Eq. (7).

* σ = surface charge density of the clay

Referring to Fig.4, these conditions are expressed as:

1. When $\frac{d\psi}{dx} \rightarrow 0$ $x \rightarrow x_c$ and $\psi \rightarrow \psi_c$
2. When $\frac{d\psi}{dx} \rightarrow \infty$ $x \rightarrow 0$ and $\psi \rightarrow \infty$

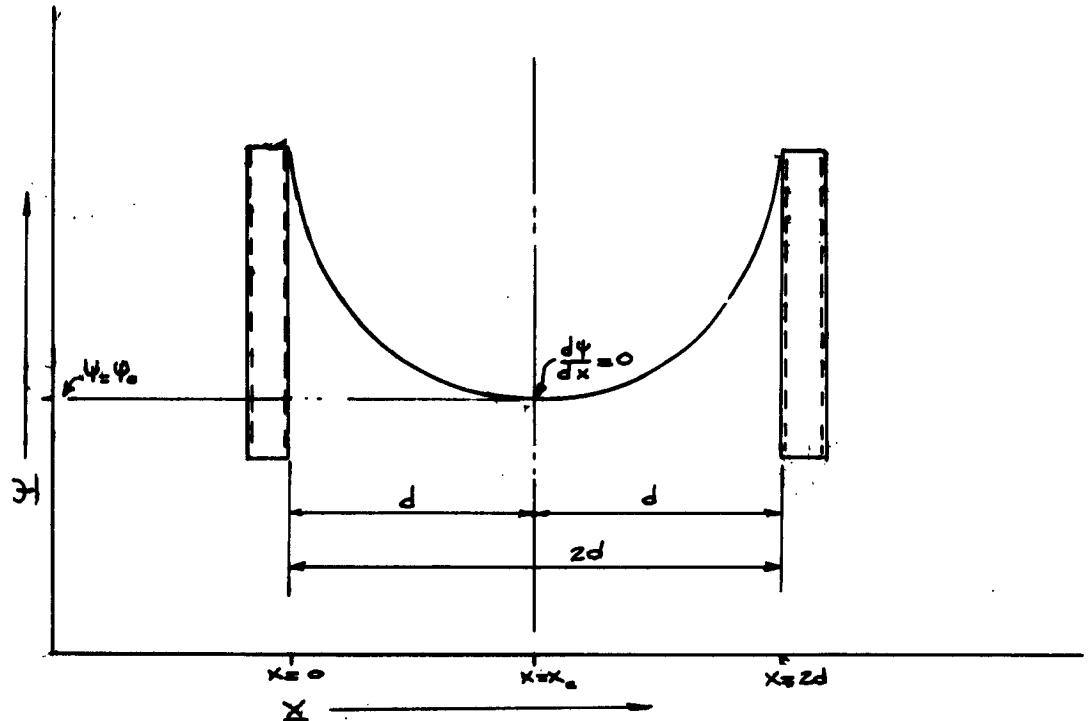


Fig.IV.Variation (Electric Potential ψ) between parallel plates

Substituting $\frac{d\psi}{dx} = 0$ when $\psi = \psi_c$ in Eq.(13)

$$\frac{dy}{dx} = -K \sqrt{2 \cosh \gamma - \cosh \gamma_c} \quad (26)$$

$$\therefore \int_{\infty}^{\psi} \frac{dy}{\sqrt{2 \cosh \gamma - \cosh \gamma_c}} = -K \int_{\infty}^{x_c} dx \quad (27)$$

The solution of Eq.(27) gives (see V  rw  y and Overbeek 1948)

$$K x_c = 2 \exp(-\gamma/2) \int_0^{\pi} \frac{d\phi}{\sqrt{1 - \exp(-2\gamma_c) \sin^2 \phi}} \quad (28)$$

$$\text{where } \sin^2 \phi = \frac{\exp(-\gamma)}{\exp(-\gamma_c)}$$

The application of Equation (28) in practice can be simplified by the substitution of the Langmuir approximation and by a summation of the potentials due to single particles. The summation of separate potentials is obtained from Equation (20) which becomes-

$$\psi_c = - \frac{4KT}{\pi \epsilon} \ln \left[\coth \left(\sqrt{\frac{2\pi \epsilon^2 n}{DKT}} \frac{x_c}{2} \right) \right] \quad (29)$$

where x_c is the half distance between particles (Referring to Fig.4 $x_c = d$). Equation (29) is valid only if $\gamma_c < 1$

The interacting region between the two planar interfaces will have a potential equal in sign to the charge on the plates. When the distance between adjacent plates is small, the number of ions with sign similar to that of the plate will be substantially reduced. The Langmuir approximation assumes that presence of ions of the same sign as the charge on the plate can be neglected. Hence Eq.(9) becomes-

$$\frac{d^2 \gamma}{dx^2} = \frac{2\pi \epsilon^2 n}{DKT} \frac{\exp(\gamma)}{2} \quad (30)$$

$$= K^2 \frac{\exp(\gamma)}{2}$$

$$\therefore \left(\frac{d\gamma}{dx} \right)^2 = K^2 \exp(\gamma) + C \quad (31)$$

Referring to Fig.4 when $\frac{d\gamma}{dx} = 0$, $\gamma = \gamma_c$

$$\therefore \left(\frac{d\gamma}{dx} \right)^2 = K^2 [\exp(\gamma) - \exp(\gamma_c)] \quad (32)$$

$$\therefore \frac{d\gamma}{dx} = - K \sqrt{\exp(\gamma) - \exp(\gamma_c)} \quad (33)$$

$$\text{and} \int \frac{d\gamma}{\sqrt{\exp(\gamma) - \exp(\gamma_c)}} = - \int K dx \quad (34)$$

$$\text{let } u = \exp(\gamma) \quad (35)$$

$$\therefore \ln(u) = \gamma$$

$$\text{Differentiating } \frac{1}{u} du = d\gamma \quad (36)$$

Substituting (36) in (34)

$$\frac{du}{u/u-u_c} = -K dx \quad (37)$$

Integrating both sides of (37) and substituting (35)

$$-Kx = 2\exp(-\gamma_c/2) \tan^{-1} [\exp(\gamma - \gamma_c) - 1]^{1/2} + C \quad (38)$$

From Fig.4 when $x=0$, $\gamma=\infty$ and $\tan^{-1}\infty = \pi/2$

$$-Kx = 2\exp(-\gamma_c/2) \tan^{-1} [\exp(\gamma - \gamma_c) - 1]^{1/2} - \pi \exp(-\gamma_c/2) \quad (39)$$

To obtain an expression for the potential at mid-plane the following values are established:—

$$\text{When } \gamma = \gamma_c, \quad x = x_c$$

$$\therefore -Kx_c = -\pi \exp(-\gamma_c/2) \quad (40)$$

$$\gamma_c = 2 \ln \left(\frac{\pi}{Kx_c} \right) \quad (41)$$

$$\text{Substituting for } \gamma \quad \psi_c = \frac{2KT}{ze} \ln \left(\frac{Kx_c}{\pi} \right) \quad (42)$$

valid only when $\gamma_c > 1$

The accuracy of the approximation methods are demonstrated in Table I from which it is evident that as the Langmuir approximation becomes untrustworthy, the summation

of separate potentials may be successfully applied.

| χ_{Y_c} | Y_c from Eq. 28 | Y_c from Langmuir | Y_c from potentials |
|--------------|-------------------|---------------------|-----------------------|
| 4 | 0.15 | -- | 0.15 |
| 3 | 0.40 | 0.10 | 0.40 |
| 2 | 0.98 | 1.03 | 1.10 |
| 1.5 | 1.50 | 1.48 | 1.70 |
| 1.0 | 2.30 | 2.38 | 3.10 |
| .75 | 2.85 | 2.86 | 4.1 |
| .50 | 3.60 | 3.68 | 5.6 |

Table I.

Comparison of midpoint potential from
Langmuir approximation and summation
of separate potentials.

By using the equations derived above (viz. (29) and (42)), it is possible to predict the effect of such variables as ionic concentration, valence, and temperature of the liquid phase of a well oriented pure clay-water system on the electric potential between mineral particles.

It should be emphasized at this point that the writers have been careful when referring to the use of the Gouy-Chapman theory for analysis of soil water interaction to limit its applicability to certain particular clay-water systems. For the Gouy-Chapman theory to be quantitatively applied to soil

water systems the basic assumptions made in its derivation must be satisfied. Not all clay minerals are plate shaped and have^a negative charge at their faces. In addition, the degree of randomness in particle orientation plays an important role in the effectiveness of the theory's application. Commonly occurring clay minerals (particularly montmorillonite) have a high surface charge density and the theory is generally applied to soils consisting of such minerals. It can be seen that flocculated soil suspensions in which a high degree of randomness in particle orientation exists, do not satisfy the basic assumption. Such an arrangement would tend to be present in a Kaolinite mixture due to the presence of edge charges and attractive forces. However, if the system is sufficiently dispersed, a qualitative analysis of soil water interaction can be arrived at by using the Gouy-Chapman theory to determine certain components of particle reaction. On the other hand, dispersed clay water systems consisting of Montmorillonite minerals in which there is a high degree of particle orientation, justify application of the Gouy-Chapman theory if the ionic concentration of the pore water is low and the electrolytes are monovalent. When the ionic valence is greater than unity the particles aggregate into small packets which act in unison.

Montmorillonite clays are known for their high swelling properties. When such a soil is wetted a large

volume increase takes place. If this volume increase is restricted, a pressure is developed and is generally referred to as the swelling pressure. This effect is attributed to the movement of water into the area between particles in attempting to satisfy the diffuse double layer requirement of the individual clay minerals. The area between the adjacent particles has a higher solute concentration than in the external solution, and these ions are unable to diffuse freely into the bulk solution. As a result, an osmotic effect is established and can be expressed quantitatively by the equation of Vant Hoff, which states:

$$P = kT (n_i - n_o) \quad (43)$$

Where P is the force per unit area required to keep individual particles at a spacing of $2d$ as in Fig.4.

From Eq.(2) $n_i - n_o \propto \exp\left(\frac{ze\psi_i}{kT}\right)$

considering both anions and cations of a symmetrical

electrolyte $n_i = n_o \left[\exp\left(+\frac{ze\psi_i}{kT}\right) + \exp\left(-\frac{ze\psi_i}{kT}\right) \right] \quad (44)$

$P = 2kT n_o (\cosh \gamma_c - 1) \quad (45)$

The swelling pressure as expressed in Equation (45) is a measurable quantity in a pure clay water system. Hence, it is possible to compare measured and calculated values by the use of Equation (45). This has been done successfully and

has been found to be in close agreement.

There have been a number of questions raised as to the validity of the equations derived in the Gouy-Chapman theory. Equation (3) states that the work required to bring an ion into the region of the charged plate is attributed solely to the potential energy of the ion with respect to the faces of the plates. However, the Coulombic energy of the ion in the electric field resulting from interaction between particle and counter ion, the polarisation energy of the ion in the electric field, the energy of electric interaction between ions, and the repulsive energy resulting from short range interaction between ions have been neglected. These energies, at first glance, would appear to contribute a substantial percentage of the work required to bring an ion into the diffuse double layer. However, Bolt 1955, concludes that the above energies tend to cancel each other and that the Gouy-Chapman theory can be accurately applied to colloid systems where the surface charge density does not exceed-

$$2 - 3 \times 10^{-7} \frac{\text{Ae}}{\text{Cm}^2}.$$

Another apparent fallacy is that the dielectric constant of the media separating adjacent plates is constant. In applying Equations (29) and (42) to physical models, the value of dielectric constant "D" is taken as that of the solvent. The effect of electrolyte concentration on dielectric constant of aqueous suspension is well known. (Hasted et al 1948). The ionic concentration in the diffuse double layer is greater

than in the external solution and increases as the face of the charged plate is approached. From this it would appear that substitution of the standard value of "D" (i.e. that of the solvent) in Equation (29) or (42) should yield a variation between calculated and measured values of potential ψ . The field strength within the diffuse double layer is relatively high, and one would expect further variation in dielectric constant in this area due to dielectric saturation. The effect of dielectric saturation has been investigated by Graham 1954 who finds that correction of the dielectric constant is unnecessary, and that by using the solvent value of "D" in the Gouy-Chapman theory, close agreement between measured and calculated values will be obtained. Although the dielectric constant in the diffuse double layer is not in fact constant, the effect of its variation within the diffuse double layer does not make itself felt on the measurable quantities. As to the validity of the Gouy-Chapman theory, the writers find support from Grahams 1954 who states that-

"The classical theory of the double layer is more reliable in practice than has been generally supposed or than one might expect from the rather dubious character on which the assumptions are based. In particular, the theory assumes that the work needed to transport an ion of charge ze

"from the interior of the solution to a region of potential ψ is $\pm e\psi$. The potential ψ is assumed to vary along one coordinate only and is supposed to be influenced by the approach of the ion in question. These are assumptions inherent in the use of the Poisson Boltzmann equation and are therefore fundamental to the Debye Huckel theory of interionic attraction as well. The success of that theory gives proof of the practical validity of the above stated assumptions regardless of their debatable logical function."

However, the Gouy-Chapman theory has never been verified for variation in temperature. Since this theory can be accurately applied to certain pure clay-water systems to explain interparticle action under normal conditions, and since an understanding of soil-water interaction at depressed temperatures is required, it is necessary to test experimentally the validity of the theory at depressed temperatures. A portion of the study will deal with an analysis of the Gouy-Chapman theory for depressed temperatures. Experiments have been devised so that measured values of swelling pressure can be compared to the values calculated from Eq. (29) (42) and (45). At the same time the effect of temperature on the swelling pressure of a well oriented pure clay water system can be evaluated.

EXPERIMENTAL ANALYSIS

Since the Gouy-Chapman theory is to be tested by evaluating the effect of temperature on the swelling pressure of a saturated montmorillonite system, the conditions of testing in the laboratory must at all times conform to the basic assumptions of the theory. To attain this, it was necessary to design a system by which temperature controlled measurements of the swelling pressure of a well oriented pure clay sample could be obtained at various ionic concentrations and particle spacings. The preparation of oriented clay samples requires special technique which is described later under the section headed "Sample Preparation".

APPARATUS. The apparatus* consists of 2 portions-

- A. A plexiglass swelling chamber enclosed in an insulating box containing a constant temperature bath and a freezing coil.(Fig.1 Appendix).
- B. An external system of valves and pressure tubing connected to the above and to a mercury manometer and compressed air cylinder.
(Fig.2 Appendix).

Section "A" of the apparatus contains the soil sample and allows for expansion and contraction of the soil sample at various temperatures. The amount of expansion or contraction and the pressure in the swelling chamber is recorded in Section "B" of the apparatus.(Refer Fig.2 Appendix).

* Figures and pictures of apparatus, etc. are to be found in the Appendix.

The swelling pressure chamber consists of a plexiglass cylinder (I.D.1.25", O.D.2.25") with a removable cap at one end which is held in place by two $4\frac{1}{4}$ " dia. $\frac{1}{4}$ " thick brass plates bolted together by four $\frac{1}{4}$ " ϕ brass bolts. Inside the cylinder there is a small stainless steel piston which can be moved along the length of chamber by forcing or withdrawing mercury through the inlet provided on the side of the chamber just above its base. The inlet is connected to the external system (Fig.2 Appendix) through the constant temperature bath and insulating box. The cap of the cylinder is made of plexiglass and consists of a porous stone and an inlet at the top for saturation of the porous stone. A porous stone is also set in the face of the stainless steel piston and can be saturated through the opening at the base of the chamber which is connected to the piston by means of a coiled Tygon tube. The tolerance between the circumference of the stainless steel piston and the walls of the chamber is .005". Temperature measurements are made within the chamber by means of a copper constantin thermocouple which passes through the cap and sits on the face of the porous stone.

When the plexiglass swelling chamber is assembled, it sits in a constant temperature bath surrounded by a freezing coil. The freezing coil is capable of operating from room temperature to -40° F. with a minimum fluctuation

of .5° F. The constant temperature bath is insulated and contains an agitator and thermometer. The soil sample is placed in the swelling chamber between the porous stone of the cap and that of the stainless steel piston and can be saturated by introducing the saturating fluid at (13) and applying a vacuum at (6). (Refer Fig.1 Appendix). Inlet (13) is connected to the salt solution source which is made accessible by using valve (A). (Fig.2 Appendix). Inlet (6) is connected to a vacuum pump by way of a salt solution trap which allows the saturation fluid to be collected and removed for analysis after it has been passed through the soil sample.

Due to the necessary insulation, when the apparatus is in operation volume changes of the sample cannot be observed in the chamber. Referring to Fig.2 Appendix, the heavy lines in the system indicate that this portion is saturated with mercury and as a result any change of volume occurring in the chamber will be indicated by either a rise or fall of the level of the mercury in Column (3). The ratio of the cross-section of area of the chamber to that of Column 3 is such that a small volume change of the sample in the swelling chamber will cause a large change in the level of mercury in Column 3, thus, allowing an accurate measurement of the volume change of the sample to be obtained. The piston is moved up and down in the chamber by varying the pressure on the mercury

in Column 3 by use of valves (J) (K) (M) and (N). The mercury manometer is used to record the swelling pressures and can measure pressures in excess of 10 atmospheres to the nearest millimeter of mercury. The swelling pressure of the soil sample is measured in Column 2. Column 3 can then also be used in the measurement of swelling pressure, but its use will tend to yield less accurate values than by Column 2.

SAMPLE PREPARATION

Samples are made up from the less than two micron fraction of Wyoming Bentonite, supplied through the courtesy of the G.F.Pettinos Co. Ltd. This particular clay has been found to contain very little impurity and the only initial purification required before separating the less than two micron fraction consists of washing the raw clay in distilled water. Separation of the less than two micron fraction consists of dispersing a small amount of the clay in distilled water (less than 2% clay by weight) and siphoning off the upper portion of the mixture at selected intervals of time. Stokes law is used to obtain the approximate depth at which siphoning should take place. The clay is then rendered homo-ionic by passing the collected supernatant through N_2 - saturated exchange resins.

A parallel oriented sample is obtained by allowing the clay suspension to settle slowly in a small plexiglass

tube which has its bottom end sealed by a cellophane membrane. The plexiglass tubes are placed on top of a drying oven with an air space being provided between the cellophane membrane and the top of the oven. Evaporation takes place slowly resulting in a wafer-like clay plate which can be removed from the tube by removing the cellophane membrane. The plexiglass tubes are $1\frac{1}{4}$ " long and have an internal diameter such that the clay wafer can be fitted neatly into the swelling chamber. Individual samples consist of several wafers stuck together by spreading a thin film of distilled water over the face of each wafer and pressing them together.

PROCEDURE.

The apparatus is first calibrated for the experimental conditions so that inherent effects of the system such as that of temperature on the volume change of the mercury in the swelling chamber can be allowed for. A brief outline of the procedure for measuring swelling pressure with the apparatus follows: (Refer to Fig.2. Appendix). The swelling chamber is assembled in the constant temperature box with the freezing coil and accessories in place. The chamber is connected to the external system through the insulating box and the mercury lines saturated. The stainless steel piston is brought to the zero position by allowing mercury to enter the chamber (through (7) Fig.1 Appendix), and the level recorded in Column 3. The porous stones and

saturation lines are saturated with distilled water. Millipore membranes cover the porous stones to prevent them from becoming clogged with clay. The sample is placed in the chamber and the cap bolted securely into position. The sample is then saturated (Valve C closed) with distilled water (a small volume change takes place in the sample during this process). On saturation, which can be predicted by observing the pressure gauge, the sample is slowly expanded to a predetermined value by opening valve (C) and (H) and using the compressed air cylinder and valves (J) (K) (M) and (N). When the required expansion has been obtained all valves are closed and salt solution is passed through the sample by opening valves (A) and (B) and applying vacuum until analysis of the solution in the trap indicates that the sample has been effectively saturated.

The swelling pressure of this volume expansion is obtained in the following manner:

When the reading on the pressure gauge is constant, the mercury manometer is pumped up by the compressed air cylinder to a pressure slightly greater than that indicated on the pressure gauge. The manometer is then allowed to exert this pressure on the soil sample through Column 2. Since valves (A) and (B) have been closed previous to this time, no compression of the sample will take place. The excess pressure of manometer is slowly dissipated through (F) and (G)

until a small movement in the level of mercury in the glass capillary portion of Column 2 is observed. (The mercury level here is always kept at the same level as that in the chamber). As a change in level 2 occurs, valve (G) is shut and the manometer reading is obtained. This value is the swelling pressure of the sample for the particular temperature, salt concentration and soil volume.

The temperature of the sample is then decreased to a predetermined value for this soil water system and the swelling pressure is obtained as described. Swelling pressures will be obtained for several temperatures, particle spacings and salt concentrations. These will be compared with calculated values obtained from Eqs. (29) (42) and (45). The salt concentration will range from .01M to .001M Na Cl and temperatures from room temperature to -10°C or lower if necessary. The degree of particle orientation obtained in the special preparation of sample can be checked by checking the system for hysteresis losses.

The volume expansion of the sample can be related to individual particle spacing if the dry weight and thickness of the clay plate, and the volume of soil and water in the chamber are known at all times. Such properties of the clay as cation exchange capacity, and specific surface area of the clay used in the experiments will be available from a separate study being carried out on the permeability of clays.

This study will also provide X-ray diffraction studies of the clay which will be useful in checking interparticle spacings in the swelling chamber.

CONCLUSION

An apparatus which will measure efficiently the swelling pressure of a well oriented pure clay water system at depressed temperatures and various salt concentrations has been designed and constructed in an attempt to evaluate soil-water interaction at depressed temperatures. At the same time the work will provide an analysis of the validity of the Gouy-Chapman theory for depressed temperatures.

The Gouy-Chapman theory is well known for its application to clay soils in explaining soil water interaction at normal temperatures and conditions. However, the theory has never been verified for change in temperature and predicts that as temperature decreases, the swelling pressure also decreases. The writers believe that swelling pressures will decrease as temperature decreases, in accordance with the theory, until the critical temperature at which the pore water freezes is reached. This temperature should be marked by an increase in pressure.

Studies relating the quantity of unfrozen water in a frozen soil-water system with initial water content (Yong 1960) have shown that the degree of particle interaction resulting from interparticle forces of attraction and repulsion

plays an important role in soil freezing. The extent to which interparticle forces can be felt can well be measured by isolating these forces - as such has been the case for this study. Existing theories fail to provide for temperature corrections in most cases and unless extensions of these theories are made, computations of resultant interparticle action from theoretical considerations cannot be made with full confidence.

The writers propose to study a particular purified clay whose properties are well known and have examined the Gouy-Chapman theory with specific reference to temperature effects.

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A P P E N D I X

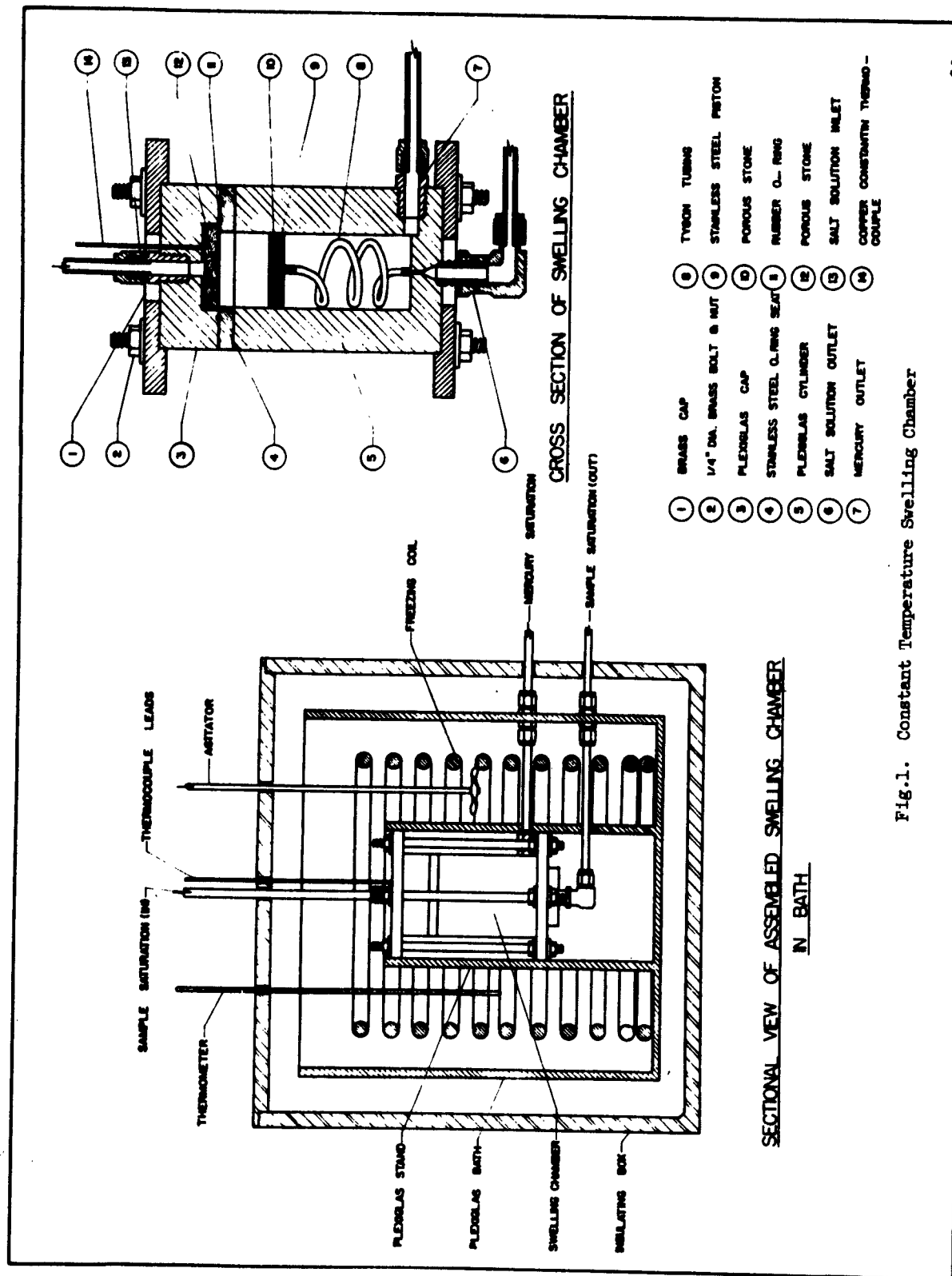
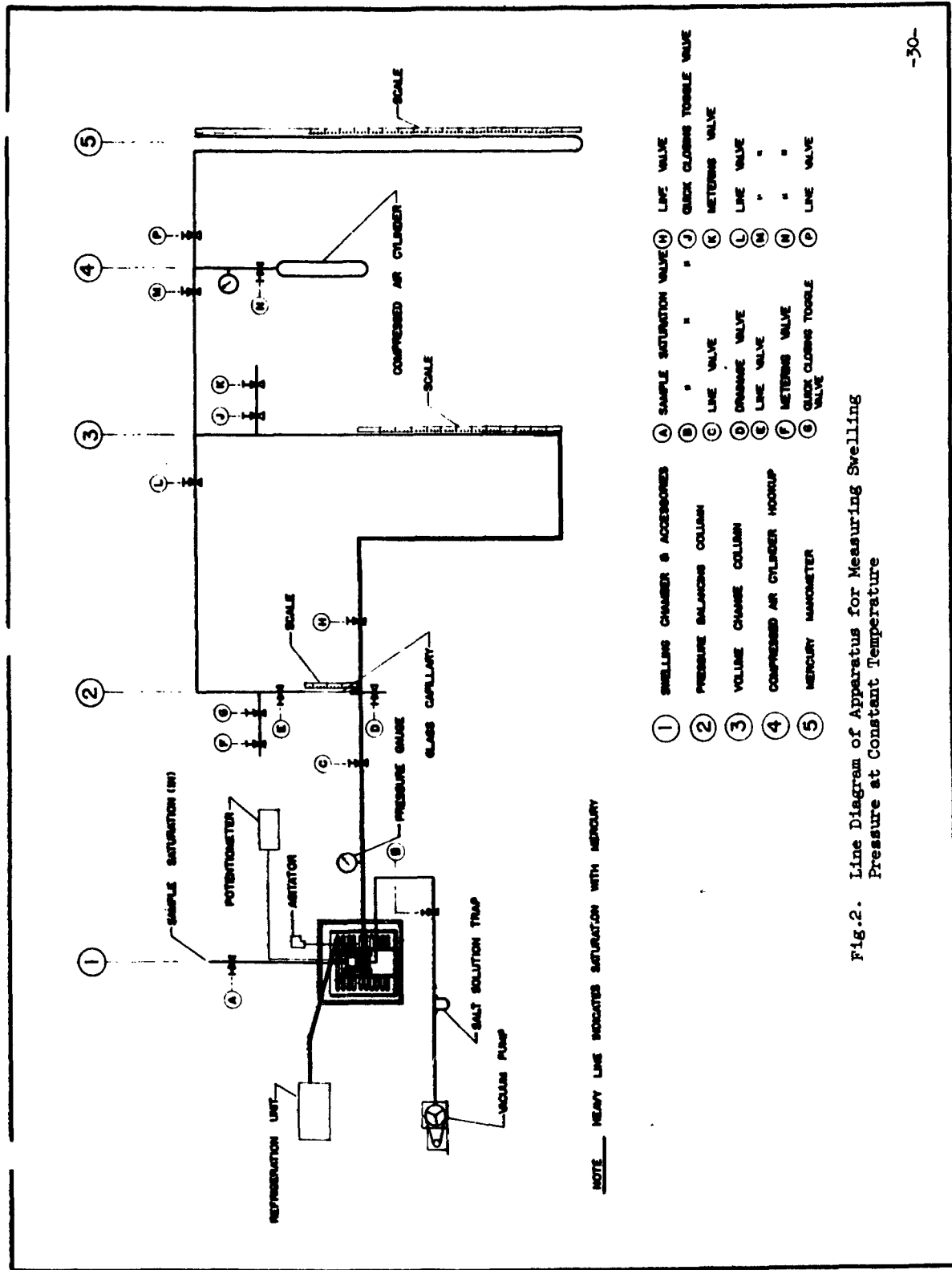


Fig.1. Constant Temperature Swelling Chamber



- | | | |
|----------------------------------|-----------------------------|-----------------------------|
| ① SWELLING CHAMBER & ACCESSORIES | ④ SAMPLE SATURATION VALVE | ⑧ LINE VALVE |
| ② PRESSURE BALANCING COLUMN | ⑤ " " " | ⑨ QUICK CLOSING TOSSE VALVE |
| ③ VOLUME CHANGE COLUMN | ⑥ LINE VALVE | ⑩ METERS VALVE |
| ④ COMPRESSED AIR CYLINDER HOORUP | ⑦ DRAINAGE VALVE | ⑪ LINE VALVE |
| | ⑧ LINE VALVE | ⑫ " " |
| | ⑨ METERS VALVE | ⑬ " " |
| | ⑩ QUICK CLOSING TOSSE VALVE | ⑭ LINE VALVE |

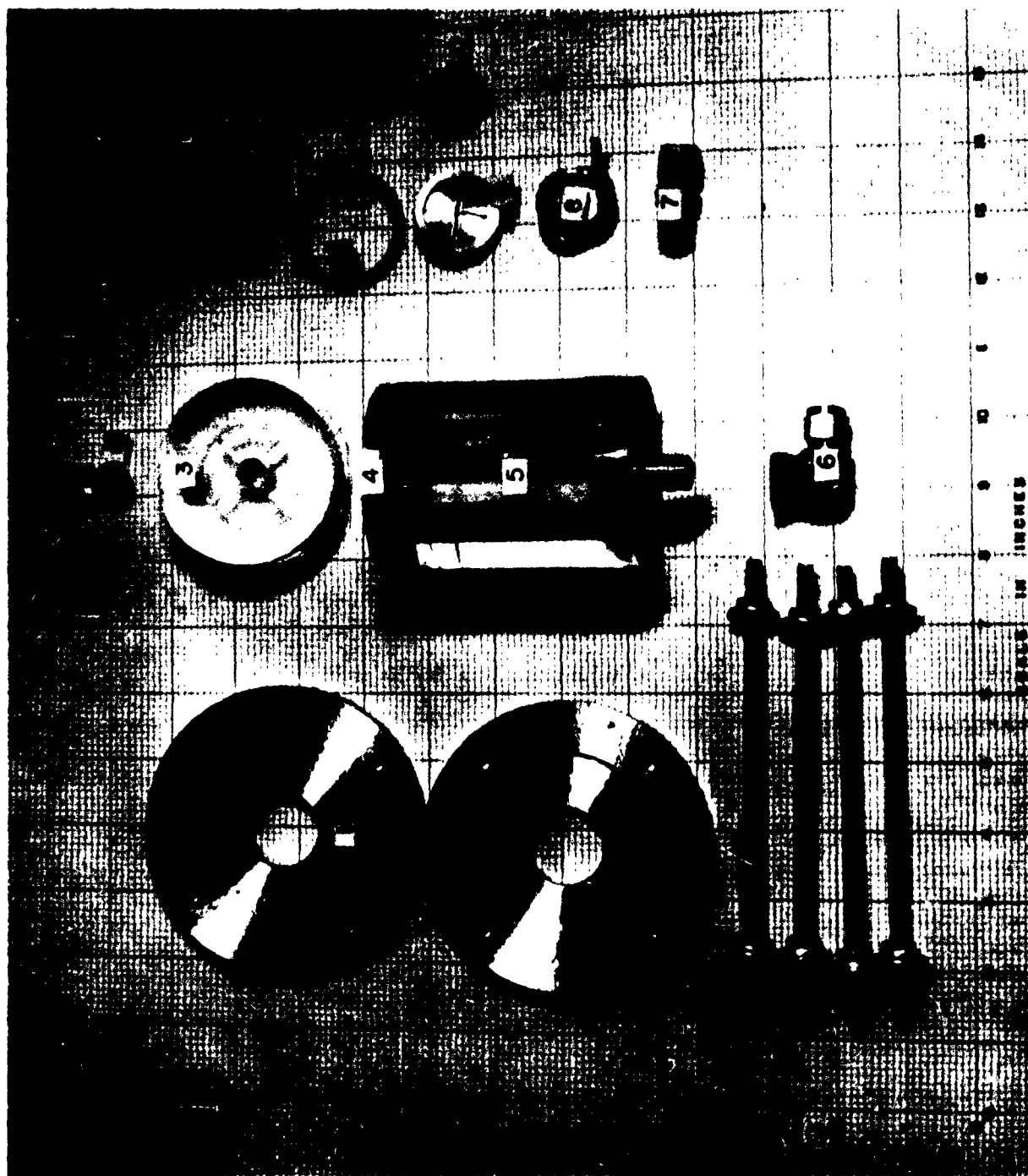


Fig.3. Components of Swelling Chamber